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(19)

(54) METHOD FOR MAKING SHAPED ARTICLES FROM SPRAYED MOLTEN METAL

(71) We, OSPREY METALS LIMITED, a British Company, of Red Jacket Works, Milland, Neath, Glamorgan SA11 1NJ, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the provision of a method for producing individually shaped workable preforms of metal by which we mean preforms from which precision metal articles can be made with only a small amount of finish machining and/or heat treatment. In this specification the word metal is used in a generic way to include not only substantially pure metals but also to include alloys.

By means of this invention, articles of complex shape in three dimensions can be produced e.g. gears, levers, cutting tools, impeller blades, rocker arms etc. Currently such articles are usually produced either by conventional forging processes or by powder metallurgical means. In either case many, and often expensive, process operations are required to convert molten metal into a "worked" article (i.e. an article formed by forging, pressing, extrusion or like operations).

A known method of manufacturing such articles, (our U.K. Patent No. 1,379,261) comprises pouring the molten metal or metal alloy, through a hole in the base of a refractory tundish (or through a hole in the base of a melting furnace or a holding furnace), atomising the stream of molten metal by means of high velocity jets of gas, or gases, (e.g. nitrogen, argon, mixtures of gases, etc.) and directing the resulting spray of hot metal particles at a suitably shaped collecting surface or die, to form a coherent deposit which is then worked in that die to produce a precision article and the present invention forms a further development of the invention protected in our earlier patent.

Our experiments have shown that there are many problems associated with the rapid spray deposition of high melting point metals (i.e. metals with melting temperatures greater than 600°C). If the sprayed deposit produced, that is to say the preform, is to have the required properties to enable it to be successfully worked to form a useful metal article. We have found that the success of the working operation depends on the sprayed preform possessing certain well defined properties which can be achieved only by ensuring that a critical and controlled amount of heat is extracted from the spray of atomised particles during the spraying operation and on deposition by the atomising gas which is cold relative to the temperature of the hot metal particles.

During the spraying operation a stream of molten metal is atomised by high velocity relatively cold gas to form a spray of hot metal particles which are cooled to a certain extent by the cold gas. Thereafter as the particles are deposited on a collecting surface they are further cooled by the action of the gas. The underlying idea of this invention is to determine the temperature and flow rate of the high velocity gas so as to extract a critical and controlled amount of heat from the atomised particles not only during flight but also on deposition so that the solidification of the preform is not dependant on the temperature and/or the thermal properties of the collecting surface which is in the form of a mould.

It will be understood from the above that if insufficient heat is extracted from the spray during flight and on deposition then the metal particles immediately after deposition are at too high a temperature and a molten or partially molten pool of metal forms on the top surface of the preform as it builds up in thickness. We have found that this often leads to the structure near the top surface appearing as a cast microstructure and typical shrinkage porosity may be present. In addition, the topography of the top surface of the deposit can be very irregular due to the effect of the atomising gas which can deform the molten surface layer of the preform during the spraying operation and in severe cases we have found that the molten metal can be blown over the sides of the mould. All of the above

effects make the deposited preform unsuitable for subsequent working.

On the other hand if too much heat be extracted from the spray of atomised particles during flight and on deposition then the particles immediately after deposition are at too low a temperature which results in poor bonding between the deposited particles. Under these conditions the preform is generally too weak and too porous for successful working. In addition, because of the porous nature of the preform it is difficult to prevent internal oxidation of the sprayed preform during its transfer to, for example, a forging press or during a reheating stage prior to its transfer to a forging press and such internal oxidation generally results in poor mechanical properties in the worked article.

Under certain conditions it is possible for the particles to be deposited very hot yet poor inter-particle bonding still occurs due to the already deposited metal being too cold.

It is the nature of the deposition process which is critical in this invention because the atomised particles do not merely "fall" on top of each other to form a typical, layered, particulate, porous type microstructure as in more conventional metal spraying processes. In this invention, the particles arrive at the collection mould in such a condition that welding to the already deposited metal is complete and all evidence of interparticle boundaries is lost. Any gaps left between the particles (which is only to be expected during a spray depositing process because the particles do not fit together perfectly) are penetrated and filled by the arrival of subsequent particles at the collecting surface, and a highly dense sprayed preform is therefore produced. To achieve this high density, non-particulate preform microstructure it is essential to control both the temperature distribution and "the state" (liquid/solid, partly liquid/partly solid) of the atomised particles on deposition and also the temperature and "state" of the surface of the already deposited metal. Clearly, if two metal surfaces are to weld together the heat contents of both surfaces are important and only by maintaining the correct heat contents in both the depositing particles and the already deposited metal can effective inter-particle welding be completely achieved and at the same time, the inter-particle "gaps" be penetrated and filled so as to form a highly dense, closed pore, non-particulate sprayed deposit. This state of affairs is only achieved if the atomising gas extracts a critical amount of heat from the particles both during flight and on/after deposition. Thus the atomising gas controls both the heat content of the particles in flight and the heat content of the surface of the already deposited metal.

It is therefore the main object of the present invention to provide a method for manufacturing from liquid metal by spray deposition individually shaped workable preforms, i.e. preforms which are substantially non-particulate in nature, which are free from segregation, which are over 95% dense and which possess a substantially uniformly distributed, closed-to-atmosphere internal pore structure.

According to the present invention there is provided a method of manufacturing from liquid metal an individually shaped workable preform which is substantially non-particulate in nature, which is free from segregation, over 95% dense and possesses a substantially uniformly distributed, closed to atmosphere internal pore structure comprising the steps of atomising a stream of molten metal to form a spray of hot metal particles by subjecting the stream of molten metal to high velocity, relatively cold gas directed at the stream, directing the spray of particles into a shaped mould to form within the mould a discrete spray-deposited preform of desired dimensions, the temperature and flow rate of the gas being determined so as to extract a critical and controlled amount of heat from the atomised metal particles both during flight and on deposition, whereby the solidification of the preform is not dependant on the temperature and/or the thermal properties of the mould.

In a prior method (U.K. Patent Specification No. 1,270,926) a wire flame spraying process is utilised to spray deposit metal particles for the relatively slow production of small metal ingots. In this process solid metal wire is melted by hot gases and the solidification of the molten metal particles is brought about by the deposition mould being cooled, or being of such thermal capacity, or both, that solidification is promoted. In the present invention, however, a critical amount of heat is extracted from the metal particles by means of the relatively cold atomising gas, or gases, so that coherent deposits of sprayed metal of any thickness can be rapidly produced without the formation of a molten, or partially molten, layer on the top surface of the sprayed deposits. Therefore, by means of the invention described here the solidification of the metal particles is not dependent on the thermal properties and/or temperature of the collecting surface.

In a prior method (U.K. Patent No. 1,262,471) for the production of metal shapes of long length and relatively thin section (e.g. strip material) it is essential that the cross-sectional geometry of the sprayed layer closely resembles that of the product after it has been rolled, as small variations can result in cracking of the product due to excessive tensile forces. This is not the case in the present invention as surplus deposited material can flow out between the shaped dies during the forging, pressing or like forming operation and can then be removed, for example,

by the shearing action of two suitably designed dies as they are loaded against each other. In addition, by means of the present invention individual shaped metal articles of precise dimensions can be rapidly produced from preforms in a single densifying and working operation. This is not the case with the production of strip material in which several rolling operations are usually required and the semi-finished strip product is normally subjected to further forming operations before finished articles are produced.

One or more sprays of hot, metal particles may be employed to obtain the required rate of deposition and/or the required area of deposition. In those cases which involve several sprays, they may be employed to act either simultaneously, or consecutively, to produce the required shape and mass of the preform. These objectives may also be achieved by relative movements between the deposition die and the spray (or sprays) of hot, metal particles.

Articles can be produced in accordance with this invention in most ferrous or non-ferrous metals or alloys which can be melted and atomised; e.g. carbon steels, alloy steels, aluminium, aluminium alloys, brasses, phosphor bronze, aluminium bronze, nickel based and cobalt based alloys. In addition, articles can be fabricate from a mixture of metals which are not mutually soluble in the liquid state, as is the case with some of the existing powder metallurgical methods.

In utilising the method of the invention, the mixing of the different metals can be achieved by spray depositing dissimilar metals either simultaneously, so that mixing of the particles occurs whilst they are in flight, or one after the other so that a sprayed deposit is produced with a structure which consists basically of layers of dissimilar metals. If desired, metallic and/or non-metallic powders, fibres, filaments or whiskers can be incorporated in the sprayed deposit during the deposition operation.

It is known that one of the problems with conventionally forged articles is that the mechanical properties can vary considerably with the direction of testing. This is not generally true for powder-forged articles which usually possess effectively isotropic mechanical properties. Unfortunately, although isotropic, some of these properties, particularly impact strength, tend to be relatively low compared with those of conventional forgings. However, articles produced by the method of the present invention possess mechanical properties which are isotropic and which also compare favourably with those of conventional forgings. Obviously, in the case of extruded articles, directionality will always exist, irrespective of the method of production.

Four examples of the production of forged metal articles and the properties which result by means of this invention are given below: —

EXAMPLE 1

A 3″ diameter bevel gear was produced by means of the invention. Molten mild steel at approx. 1600°C was poured through a 3/16″ diameter ceramic nozzle at a rate of 23 lb/min. The metal stream was atomised by nitrogen gas at or just below room temperature flowing at a rate of 100 standard cubic feet/min (s.c.f./min) so that a spray of cooling metal particles was directed at a concave, solid, mild steel collecting die which was placed in the spray at a distance of approximately 11″ from the atomiser. The particles which impacted the collecting die rapidly built up (at a rate of approximately 0.08″/sec) to make a preform which weighed approximately 1.9 lb., and which was 96.5% dense; the temperature of the gas leaving the atomising chamber was about 500°C. The preform was cooled in a nitrogen atmosphere and subsequently it was reheated to 1100°C in a cracked ammonia atmosphere and forged to finished shape in one blow of 10,000 ft. lb. energy on a forging press.

The forged tensile properties of the gear shape produced by means of the invention were similar to those of one manufactured from a wrought bar billet, of identical chemical composition, as illustrated in the following table of mechanical properties.

	Sprayed/forged	Bar billet
Yield Strength (t.s.i.-tons per sq.in)	19	18
Ultimate Tensile Strength (t.s.i.)	28	28
Elongation (%)	34 (1″ gauge)	33 (1″ gauge)
Reduction in area (%)	55	55
Hardness (D.P.H. No.)	125	125

EXAMPLE 2

A. 2.5″ diameter, 0.5″ thick disc with a thick, raised rim was produced by means of the invention in Type 304 stainless steel under similar atomising and forging conditions as in Example 1. The preform weighed 0.9 lb. and was 97% dense. The mechanical properties are given below in comparison with reported values for the conventionally forged Type 304 steel.

	Sprayed/Forged	Conventional Type 304 Stainless Steel
0.2% Proof Stress (t.s.i.)	16	15.6
Ultimate Tensile Strength (t.s.i.)	40	38
Elongation (%)	65 (1" gauge)	55 (2" gauge)
Reduction in area (%)	65	65
Hardness (D.P.H. No.)	157	150

EXAMPLE 3

By means of this invention an asymmetric preform approximately 3.5"×1.25"×1.25" and weighing 1.5 lb. was produced for subsequent forging into a cutting tool. Molten En24 steel was poured through a 3/16" diameter ceramic nozzle at a rate of 21 lb/min. The metal stream was atomised by nitrogen gas at or just below room temperature flowing at a rate of 130 s.c.f./min. so that a spray of cooling metal particles was directed at a concave, solid, mild steel collecting die which was placed in the spray at a distance of approximately 9" from the atomiser. During the spraying operation the die was moved relative to the spray in order to obtain the required preform shape. The particles which impacted the collecting die rapidly built up (at a rate of approximately 0.1"/sec) to make the preform which was transferred directly to a forging furnace operating at 1250°C. The preform was subsequently removed and forged in one blow to produce the cutting tool which was then hardened and tempered. The isotropic properties achieved are compared below with those of conventional bar stock in a similar condition.

	Sprayed/ Forged	Conventional En24 Longitudinal	Conventional En24 Transverse
Yield Stress (t.s.i.)	56	56	52
Ultimate Tensile Strength (t.s.i.)	63	65	62
Elongation (%)	19	25	16
Izod Impact Strength (ft.lb.)	50	66	36

EXAMPLE 4

By means of this invention a preform of 2.5" mean diameter and approximately 1.5" high was produced in En8 steel. The preform was then upset forged at 1200°C between flat dies in order to achieve a height reduction of 30%. The forged slab produced was then normalised and the properties achieved are compared below with those of conventional En8 bar stock.

	Sprayed/Forged	Conventional En8
Yield Strength (t.s.i.)	26	26
Ultimate Tensile Strength (t.s.i.)	41	39
Elongation (%)	25 (1" gauge)	30 (2" gauge)

The invention is described further, by way of example, with reference to the accompanying drawings, in which:—

Fig. 1 is a diagrammatic elevation of an apparatus for making shaped metal preforms in accordance with the invention;

Fig. 2 is a sectional elevation through a drop-forging hammer for working the preform produced in Fig. 1;

Fig. 3 is a cross-section through the resultant forging produced by the drop-forging hammer of Fig. 2; and

Fig. 4 shows the finished precision metal article.

Molten metal (1) is poured from a heated, refractory tundish (2), through a refractory nozzle (3) and is atomised and cooled by high velocity jets of nitrogen at or just below room temperature which issue from an atomising device (4) through which the molten metal stream is poured; the atomising gas enters the atomising device via delivery pipes (5). A critical amount of heat is extracted from the spray of metal particles (6) by controlling the conditions under which atomisation occurs (e.g. by variations in the atomising gas pressure; spray distance; diameter of molten metal stream, temperature of molten metal; mass ratio of atomising gas to sprayed metal, etc.) and the pray of hot metal particles is directed at the collecting surface, or die (7), where a hot, coherent and relatively strong deposit or preform (8) is formed. After the deposition process has been completed the hot preform (8) can be removed from the collection die by means of an ejector (9). The preform (8) can then be transferred directly to the bottom die of a drop-forging hammer (10) and forged between the dies (10) and (11) to produce a forging (12) from which any surplus 'flash' material (13) can be trimmed off to produce a shaped and forged article (14). Alternatively the preform (8), after removal from the deposition die, can be forged at some later time

either with or without the addition of heat to produce a shaped and forged article.

WHAT WE CLAIM IS:—

1. A method of manufacturing from liquid metal an individually shaped workable preform which is substantially non-particulate in nature, which is free from segregation, over 95% dense and possesses a substantially uniformly distributed, closed to atmosphere internal pore structure comprising the steps of atomising a stream of molten metal to form a spray of hot metal particles by subjecting the stream of molten metal to high velocity, relatively cold gas directed at the stream, directing the spray of particles into a shaped mould to form within the mould a discrete spray-deposited preform of desired dimensions, the temperature and flow rate of the gas being determined so as to extract a critical and controlled amount of heat from the atomised metal particles both during flight and on deposition, whereby the solidification of the preform is not dependant on the temperature and/or the thermal properties of the mould.

2. A method of making a precision metal article from a preform made by the method according to claim 1 wherein the preform is worked by a die to form a shaped article.

3. A method according to claim 2 wherein the preform is removed from the collecting surface before working is carried out by the die.

4. A method as claimed in claim 2 or 3 wherein working of the preform is effected with the addition of heat.

5. A method as claimed in any preceding claim, wherein the gas is mainly nitrogen or argon, or a mixture selected from carbon monoxide, carbon dioxide, nitrogen and hydrogen.

6. A method as claimed in claim 5 wherein the gas is substantially at ambient temperature.

7. A method of manufacturing a spray deposited preform of metal as claimed in claim 1, and substantially as hereinbefore described with reference to and as illustrated in Figure 1 of the accompanying drawings.

8. A preform made by the method as claimed in any preceding claim.

9. A shaped precision metal or metal alloy article manufactured from the preform as claimed in claim 8.

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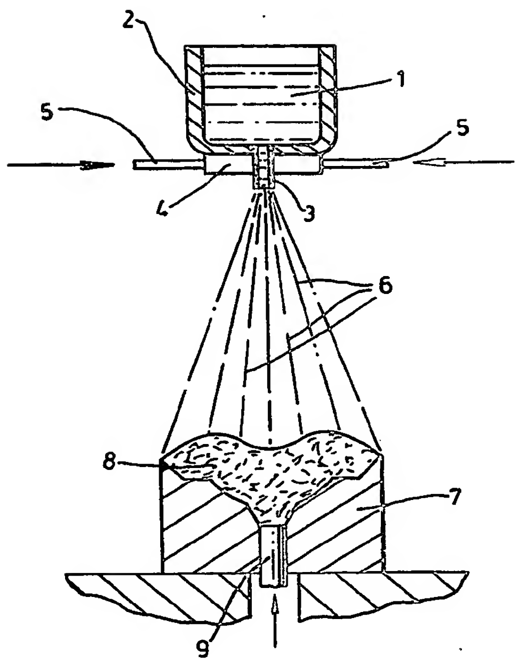
1472939 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1.



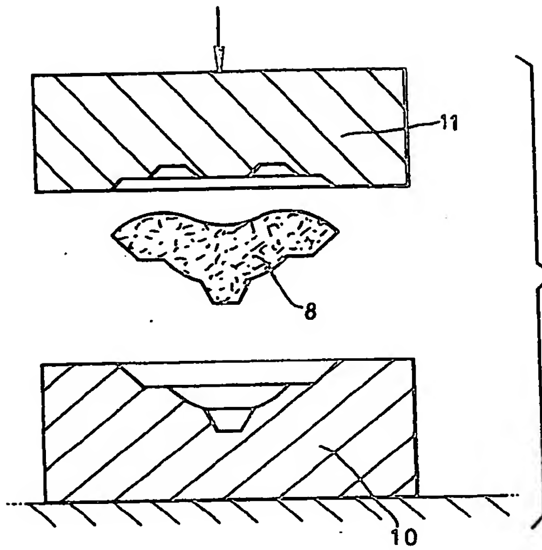


FIG. 2.

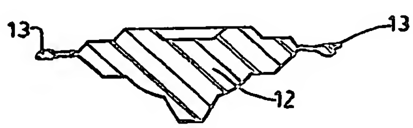


FIG. 3.

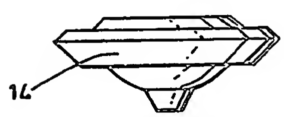


FIG. 4.